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Xianglong Yu
University of Wollongong, xly991@uowmail.edu.au

Zhengyi Jiang
University of Wollongong, jiang@uow.edu.au

Xiaodong Wang
University of Wollongong, xiaodong@uow.edu.au

Dongbin Wei
University of Wollongong, dwei@uow.edu.au

Quan Yang
University Science and Technology, Beijiang

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Abstract

The influence of the coiling temperature, ranging from 550 to 570℃, on the morphology and the phase composition of the oxide scale formed on the microalloyed low carbon steel for automobiles after hot strip rolling was investigated. Physicochemical characteristics of the oxide scales were examined and their formation mechanism was discussed. Thickness of the oxide scale is in the range of 8-11μm and decreases with a decrease of coiling temperature. The microstructure and phase composition, XRD analysis shows a large amount of magnetite (Fe3O4) and some sparse hematite (Fe2O3) exist on the surface of hot rolled strip when the coiling temperature reduces from 570 to 550℃. The coiling temperature substantially affects the internal microstructure and magnetite phase.

Keywords

rolled, effect, strip, coiling, scale, temperature, oxide, hot

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Effect of coiling temperature on oxide scale of hot-rolled strip

Xianglong Yu[1, a], Zhengyi Jiang[1, b], Xiaodong Wang[1, 2, c], Dongbin Wei[1, d] and Quan Yang[3, e]

[1]School of Mechanical, Materials and Mechatronic Engineering, University of Wollongong, Wollongong NSW 2522, Australia

[2]Shougang Research Institute of Technology, Shougang Group, Beijing, 100043, China

[3]Engineering Research Institute, University Science and Technology Beijing, Beijing 100083, China

[a]xly991@uow.edu.au, [b]jiang@uow.edu.au, [c]x_d_wcumt@163.com, [d]dwei@uow.edu.au, [e]yangquan@nercar.ustb.edu.cn

Keywords: Oxide scale, hot-rolled strip, coiling temperature, phase composition

Abstract. The influence of the coiling temperature, ranging from 550 to 570°C, on the morphology and the phase composition of the oxide scale formed on the microalloyed low carbon steel for automobiles after hot strip rolling was investigated. Physicochemical characteristics of the oxide scales were examined and their formation mechanism was discussed. Thickness of the oxide scale is in the range of 8-11μm and decreases with a decrease of coiling temperature. The microstructure and phase composition, XRD analysis shows a large amount of magnetite (Fe_3O_4) and some sparse hematite (Fe_2O_3) exist on the surface of hot rolled strip when the coiling temperature reduces from 570 to 550°C. The coiling temperature substantially affects the internal microstructure and magnetite phase.

Introduction

Metallic oxide (scale) formed on the strip surface is a significant disturbance factor during hot rolling. It is necessary to suppress and remove the oxide scale buildup. The oxide scales exhibit different morphologies and characteristics in a conventional hot strip production line, which includes a reheating furnace, descalers, a roughing mill, finishing mills, a run-out table (online cooling) and down coilers [1], as shown in Fig. 1. Generally, these oxide scales can be classified as the primary, the secondary and the tertiary scales [2].

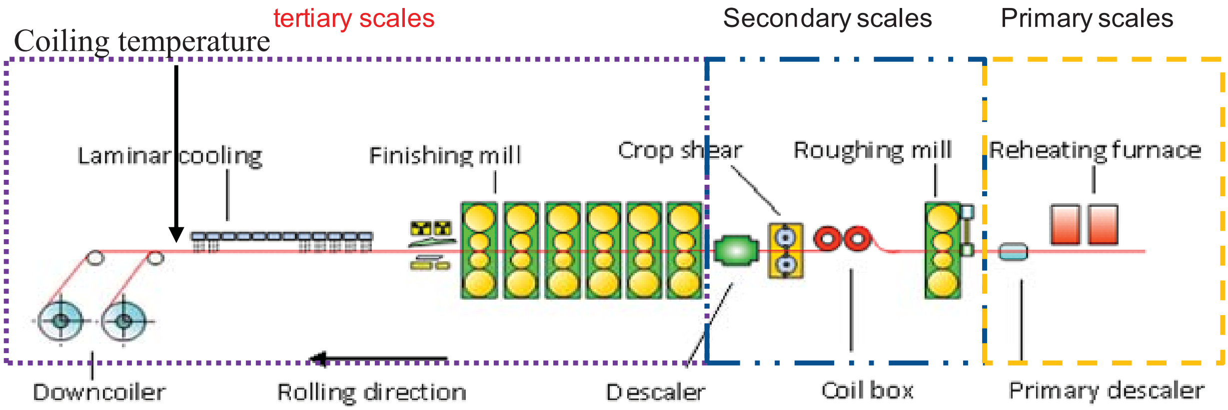

Fig.1 Illustration of a hot strip mill and classification of oxide scales

In the first stage, the surface oxides grown into a brittle oxide scale that can be up to around 3 mm thick at the temperature of 1250-1260°C in the reheating furnace. This layer of primary scale is

largely removed by a hydraulic descaling process before the roughing rolling. After the first descaling, the secondary scale developed in the temperature range of 900-1200°C grows fast, ranging from a few to less than 100 μm [3, 4], and another descaler is provided for this oxide layer before the finishing mills. Moreover, the tertiary scale generated during the finishing rolling and in the cooling process while the hot coiled strip cools down to the ambient temperature. This layer of oxide scale may evolve further and undergo structural changes if oxygen is available during cooling after coiling. The final morphology and structure composition of the oxide scale, however, also depend greatly on the coiling temperature (CT), where the strip is coiled at a down coiler, and the cooling conditions [5].

Generally, the tertiary scale formed at finishing temperature (FT), at the exit of steel strip from the finishing mills, is composed of three well defined layers (iron oxides), namely: a thick wustite (approximate composition FeO) layer adjacent to the steel substrate, then an intermediate magnetite layer, and finally a thin outermost hematite layer [6-8]. The same three layer structure is maintained until a eutectoid point of Fe-O system, a temperature of 570℃ is reached. However, when the temperature drops to 570℃, wustite becomes unstable and thermodynamically decomposes to a mixture of iron and magnetite via a eutectoid reaction [9, 10]:

$$4FeO \rightarrow Fe_3O_4 + Fe \quad (1)$$

The equilibrium state of phase transformation depends on the temperature and the cooling rate. Correspondingly, the microstructure of the oxide scale is also affected by processing parameters, such as finishing and coiling temperatures, cooling rate, and cooling conditions under which the coils are stored. Uniform structure of the oxide scale throughout the steel coils has been observed across the width and along the length of the strip [11].

The coiling temperature of microalloyed low carbon steel for automobiles, in the range of 510-590℃ covering the eutectoid point of wustite, therefore, is of considerable importance. In this work, an attempt to obtain more insight on the effect of the coiling temperature on the formation of the tertiary scale on a hot-rolled steel strip, with particular emphasis on the thickness and phase composition of oxide scale in terms of the decomposition of wustite, was established. The characterisation of the oxide layer as a function of the location in the hot-rolled coil is also discussed.

Experiment

Materials. The material used in this study was commercial hot-rolled strips from microalloyed low carbon steel for automobiles with the thickness of 7.8 mm, provided by Shougang Group, China. Samples coded as CT570 and CT550 were processed with the coiling temperatures of 570 and 550℃ respectively. The chemical composition of the samples is listed in Table 1.

Table 1 Chemical composition of commercial hot-rolled steel strip [wt.%]

C	Si	Mn	P	S	Al	V	Nb	Ti
0.1	0.16	1.4	0.012	0.005	0.080	0.004	0.021	0.002

In order to focus on the influence of the coiling temperature, other process parameters were preset constant as shown in Table 2, in which RT2 is the temperatures at exit of the rough mill. Test coiling temperature was varied in the range of 540, 550, 560 and 570°C in a real hot rolling line to obtain different types of tertiary scales in terms of properties of the testing material [12].

Table 2 Process parameters in this study

Reheating Temperature (°C)	RT2 (°C)	FT6 (°C)
1250	1040	880

Along the length of the strip, the samples were taken from the middle position of the hot-rolled coil. Then, the middle portion was split up in three parts across the width (S.1, S.2) as shown in Fig. 2. Each portion was cut in small samples, sized 2 x 2 cm^2 in order to carry out the physicochemical characterisation of the oxide scale.

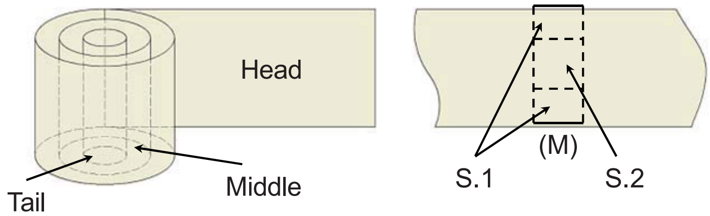

Fig.2 Scheme of the locations of the samples in the hot-rolled steel strip

Oxide scale analyses. The oxide scale morphology of the surface and of the cross-section of the samples was examined by employing scanning electron microscopy (SEM).The samples were mounted in epoxy resin, and then polished by SiC paper and diamond paste down to the diamond size of 1μm, further cleaned by distilled water and ultrasonically by ethanol. The cross section of the coupon was observed using Hitachi S-3400N (Inca Ie450). The powder of the oxide scale was analysed by Bruker D8 advance X-ray diffraction (XRD). Accordingly, the thickness of the oxide scale was measured and the phase composition was also determined.

Results and Discussion

Effect of coiling temperature on the morphology of the oxide scale. The SEM micrographs, as shown in Fig. 3, exhibit the cross section of the hot-rolled coupons produced by the coiling temperature of 570 and 550℃ respectively.

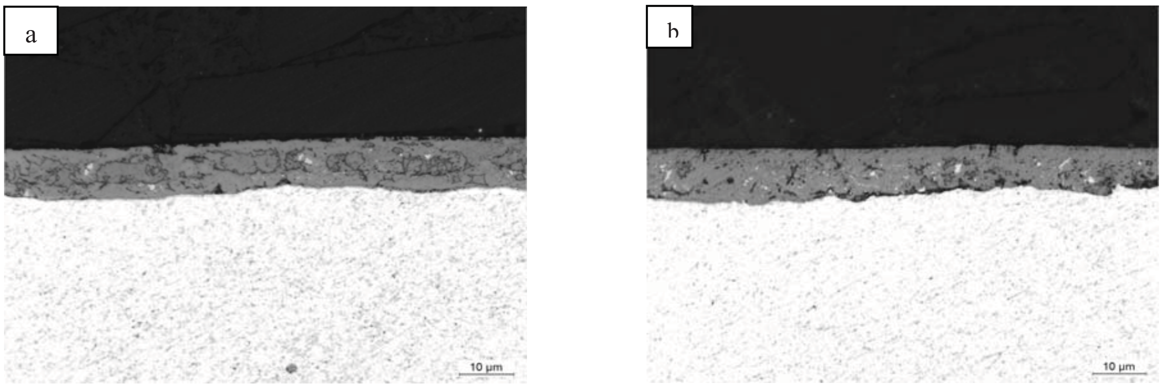

Fig.3 Morphology of oxide scale for a) CT570 and b) CT550

It is observed that the oxide scale formed on the strip at higher coiling temperature (Fig. 3a CT570 sample) is in present of the outermost thin layer of initial magnetite and major proportions of wustite next to the substrate accounted. It is possible that the eutectoid reactions rarely take place due to the higher coiling temperature, and the decomposition of wustite is suppressed so much wustite is retained at ambient temperature.

In Fig. 3b, the oxide scale developed on the strip at lower coiling temperature (Fig. 3b CT550 sample) consists of a single layer with small amount of white phase. That means eutectoid reactions proceed completely and a mixture of magnetite and α-iron exists, when the coiling temperature is lower than the eutectoid point 570℃. Only at the edge of the hot-coiled strip there exists some retained wustite. Therefore, less retained wustite and a majority of magnetite phases were demonstrated in the oxide scale at the coiling temperature of 550°C.

Effect of coiling temperature on the thickness of the oxide scale. The total thicknesses of the oxide scale at different coiling temperature are shown in Fig. 4.

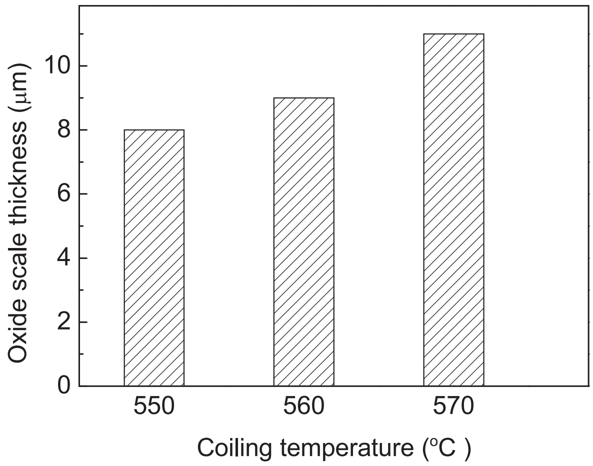

Fig.4 Thickness of oxide scale vs coiling temperature

The oxide scale generated at the lower coiling temperature is relatively thin. An increase of the coiling temperature results in thick oxide scale. The three-layered oxide scale structure on the edges of the hot-coiled strip (Sample S.1) demonstrate thick outer hematite layer, which is formed due to the rapid oxidation at high coiling temperature where oxide scale spalls. This is because the oxide scale nucleation in the initial stage was more at higher oxygen pressure before coiling, which contributed mainly to the entire thickness of the oxide scale. It is known that the oxide dust generated during the subsequent processing after hot rolling is made of this layer of hematite.

In addition, the total thickness of the oxide scale also depends on the holding time in coiling and the following cooling process. Some studies [2] confirmed the thickness of the oxide scale on low carbon steel can increase with the decrease of cooling rate.

Effect of coiling temperature on phase composition of the oxide scale. Through the XRD quantification analysis of the oxide scale, Fig. 5 illustrates the mole fraction of the iron oxide expressed as a function of the coiling temperature and the locations in the hot-coiled strip. Lower coiling temperature or the slow cooling will result in high percentage of magnetite, which is above 70% even up to 80%.

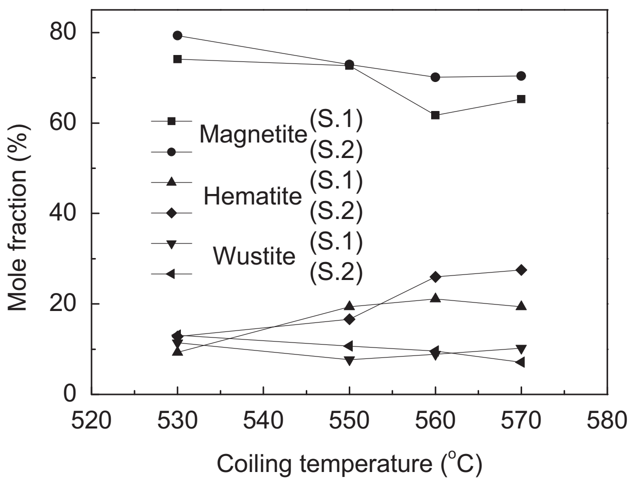

Fig.5 Phase composition of oxide scale against coiling temperature

At the coiling temperature of 550 to 570°C, the oxide scale comprised primarily magnetite with very little wustite. The percentage of hematite is about 15-30% and relatively increases with the coiling temperature. This structure is different from that of the oxide scales on pure iron at high temperature, which are normally three layered with a thick inner wustite layer, a thin intermediate magnetite layer, and a very thin surface hematite layer [6]. It is possibly resulted from the existing microalloying elements, such as manganese, silicon and chromium. They may affect the growth and distribution of magnetite and hematite layers, even the ions diffusion mechanism through the corresponding layers.

This also deduces that at the coiling temperatures below the eutectoid transition point of 570°C, the probability of the accumulation of wustite phase would significantly decreased according to thermodynamics studies of Fe-O system [10] in Fig. 6. Thus, the phase composition of the oxide scale is primarily magnetite with a slight amount of iron and hematite at the edge of the hot-coiled strip.

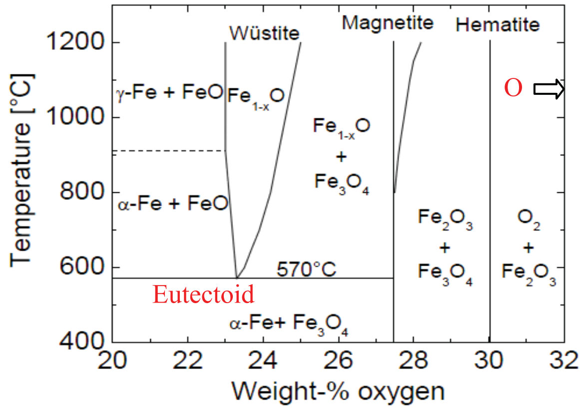

Fig.6 Fe-O equilibrium phase diagram

Greenwood and Howe [13] proposed the following reaction:

$$(1-4z)Fe_{1-x}O \rightarrow (1-4x)Fe_{1-z}O + (x-z)Fe_3O_4 \tag{2}$$

where x>z, $Fe_{1-z}O$ is an iron-rich wustite, which subsequently decomposed into a eutectoid product via the following reaction:

$$4Fe_{1-z}O \rightarrow Fe_3O_4 + (1-4z)Fe \tag{3}$$

When the temperature of hot-rolled strip goes down from the coiling temperature of above 570°C, eutectoid reactions can occur, leading to the accumulation of iron-rich wustite adjacent to the steel substrate, the intermediate transformed magnetite layer with a few α-iron precipitations, the outer layer with the minor hematite. When the coiling temperature reduces below 570°C, the oxide scale is composed of only magnetite and sparse hematite at some locations of the hot-rolled strip.

Conclusion

The morphology and phase composition of the tertiary oxide scale formed on microalloyed low carbon steel for automobiles in a commercial hot rolling line have been examined. Their formation mechanism, with particular emphasis on the influence of coiling temperature, has been analysed. The coiling temperature has a significant effect on the microstructure, the thickness and phase distribution of the oxide scale. When the coiling temperature is at 550°C below the eutectoid point of Fe-O system, relatively little retained wustite and more magnetite can be observed. With an increase of

coiling temperature, the thickness of the oxide scale and the hematite sub-layer increases slightly. Reducing the coiling temperature from 570 to 550°C, the thinner oxide scale generated. And the oxide scale transformed from the eutectoid structure comprises maximum magnetite with a few amount of iron precipitation. Therefore, it is significant to adjust the composition of oxide scale by change the coiling temperature and other cooling conditions during hot rolling.

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